INTERIM ACID DEPOSITION

CRITICAL LOADINGS

FOR

WESTERN AND

NORTHERN CANADA

Prepared for

TECHNICAL COMMITTEE
WESTERN AND
NORTHERN CANADA
LONG RANGE TRANSPORT
OF
ATMOSPHERIC POLLUTANTS

by

Interim Acid Deposition
Critical Loadings
Task Group

August 1990

ACID RAIN
PLUIES ACIDES

BC Environment

Alberta
ENVIRONMENT

Saskatchewan
Environment and
Public Safety

Manitoba
Environment and
Workplace Safety
and Health

Northwest Territories Renewable Resources

Canada

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EXECUTIVE SUMMARY

The Western and Northern Canada Interim Acid Deposition Critical Loadings Task Group, established by the Technical Committee, Western and Northern Canada Long Range Transport of Atmospheric Pollutants, was to develop and recommend a range of interim target (critical) loadings for highly and moderately sensitive aquatic and soil systems in northern and western Canada. Critical load is the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems. Target load is less restrictive than critical load, and takes into account other factors such as economic, political, or social considerations.

A target loading of 20 kg ha^{-1} a^{-1} wet sulphate for eastern Canada had been established in the early 1980's to protect moderately sensitive ecosystems, but no national standard existed to protect highly sensitive ecosystems. The Task Group was instructed to use data for highly sensitive areas of western and northern Canada with assistance from information obtained in other parts of the world to develop the critical loadings.

The most sensitive environmental component should be used to determine interim critical loadings. The use of this concept results in determining loadings which will protect the aquatic environment where these have high or moderate sensitivity. Where the sensitivity of the aquatic environment is low, loadings should protect sensitive soils. The Task Group used maps which combined aquatic sensitivity and sensitivity determined from soils and surficial geology. Four sensitivity classifications resulted. It was determined that Class 1, 2, and 3 areas should, on an interim basis, be provided the highest level of protection. Further field investigations are required, in Class 3 areas, to determine if this high level of protection is too conservative or if areas within this classification should be further refined. Class 4 areas should be provided a level to protect moderately sensitive lakes.

Acidity can be deposited in either wet or dry form. The principal acidifying precursors in precipitation are ammonia and oxides of nitrogen and sulphur. Dry deposition is considered to possibly be a significant portion of total acidic deposition; however, it is difficult to measure. Consequently, wet deposition rates will be used to predict total acidification. The acidity associated with dry deposition must be measured in areas of western and northern Canada before the interim status of the critical loading can be removed.

The precipitation characteristics on the prairies and central British Columbia are different from other jurisdictions. The major difference is that non-acidic sulphates, as well as large quantities of calcium, ammonium and magnesium occur in precipitation. A relationship has not been demonstrated between acidity and the concentration of sulphate in the precipitation of western and northern Canada. Therefore, the generation of a critical loading based on wet sulphate deposition is not applicable.

In western and northern Canada, dry particulate matter in the atmosphere can neutralize acidity in the precipitation. In addition, acidity measurements in coastal British Columbia require correction for the presence of sea-salt. Thus, the concept of **Acidifying Potential (AP)** has been recommended by the Task Group to take these factors into account and to develop critical loadings.

Although nitrification and denitrification processes produce and consume hydrogen ions, the **AP** approach assumes that the net effect in watersheds is zero if the deposited nitrogen compounds are taken up by the vegetation. Further work should be undertaken to determine if nitrogen compounds are significant acidifying components of precipitation (i.e., to determine if significant nitrate leaching occurs from watersheds).

Existing acidifying potential levels in western Canada are generally negative or are below 10 meq m^{-2} a^{-1}. The only very high values in precipitation are found in British Columbia, just north from Vancouver and near Prince Rupert. At the station near Vancouver, an acidifying potential value of about 60 meq m^{-2} a^{-1} was measured in 1987. It has been documented that acidification may be occurring at a nearby highly sensitive lake. Calculations for the loading that this lake can withstand indicate that at a loading between 55 and 67 meq m^{-2} a^{-1}, an alkalinity of 50 μeq L^{-1} can be maintained in the lake. Thus, the acidifying potential in the precipitation at this location appears to be near a level where damage to this highly sensitive lake could occur with greater loads.

An interim critical load range of 12 to 31 meq m^{-2} a^{-1}, expressed as **Acidifying Potential**, is proposed to protect highly sensitive ecosystems. These loadings are sufficiently restrictive in the short-term to protect highly sensitive ecosystems. Refinements can be made to these interim values by carrying out the recommendations contained in this report. These loadings are not intended to be applied to brown-water systems or to coastal British Columbia where the validity of this range is in doubt. For coastal British Columbia, doubts exist because of the large precipitation volumes which appear to mitigate potential impacts that might occur in other areas receiving the same load. The critical loads were derived using data for Scandinavian lakes and are selected to ensure that the pH of highly sensitive lakes does not fall below 6.0.

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1.0 INTRODUCTION

Recognizing the importance of the acidic deposition issue, the governments of British Columbia, Alberta, Saskatchewan, Manitoba, the Northwest Territories, and Canada held joint consultations in 1980 to review the available information on air pollution from western and northern Canada. It was concluded that the cumulative effects of acid rain might become a problem in the future. To protect highly sensitive ecosystems, these governments adopted a management strategy which has four basic elements: (1) determining the sensitivity of the western and northern Canadian environment to acidic deposition, (2) establishing critical loadings (standards) that are suitable for the sensitivity of this environment, (3) monitoring to ensure compliance with the targets, and (4) establishing emissions management plans as necessary (Sandhu and Wilson, 1987). A target loading of 20 kg ha^{-1} a^{-1} wet sulphate had been adopted to protect moderately sensitive ecosystems in eastern Canada but there was no national standard for the protection of highly sensitive environments.

At the direction of the western and northern Canada LRTAP Program, ESSA Environmental and Social Systems Analysts Ltd. and Concord Scientific Corporation (hereafter referred to as ESSA) completed a report dealing with critical loadings for acidic deposition in western Canada in 1987. The report provided a synthesis of existing information, and recommendations for the development of critical loadings, including those on an interim basis.

To follow-up on the recommendations, the Technical Committee, Western and Northern Canada Long Range Transport of Atmospheric Pollutants established a Task Group to develop and recommend interim critical loadings for highly and moderately sensitive aquatic and soil systems in western and northern Canada.

The terms of reference for the Task Group's activities included:

1. Develop and recommend a range of interim critical loadings for both highly sensitive and moderately sensitive aquatic and soil systems in western and northern Canada, by using data for sensitive areas of these regions, with assistance from information obtained in other parts of the world.

2. Prepare a final report providing a brief background, rationale, methodologies used, recommendations, and references. It will identify research projects to remove the uncertainty from the critical loadings in order to make them more scientifically defensible.

Critical load is defined as the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems, according to present knowledge. Presumably, if the most sensitive ecological system is protected, less sensitive systems will also be protected. The target load is less restrictive than critical

load, and takes into account other factors such as economical, social, or political considerations.

A progress report on the sensitive ecosystems and target loadings for acidic deposition in western and northern Canada has been published (Sandhu and Lechner, 1989).

2.0 THE TASK GROUP MEMBERS

Members included:

Les Swain	- British Columbia Ministry of Environment (Chairman)
Serge Dobko	- Alberta Environment
Dave Trew	- Alberta Environment
Larry Lechner	- Saskatchewan Environment and Public Safety
Max Morelli	- Manitoba Environment
Tom Brydges	- Environment Canada

3.0 BACKGROUND CONSIDERATIONS FROM THE ESSA REPORT

ESSA (1987) discussed the critical loading concept as it applied to western and northern Canada, taking into consideration scientific and practical concerns.

"Ideally, one would develop target loading standards by summing up the damages associated with a given level of deposition across all receptor components (i.e., soils, crops, forests, surface waters, wetland), or select the most sensitive component within each region based on dose/response relationships" (ESSA, 1987). However, information is not available for all receptors. Thus, selecting the most sensitive environmental component to determine critical loadings is one of the tasks addressed in this report.

3.1 FORESTRY

In terms of forest resources, ESSA (1987) reported that even in the thoroughly studied northeastern United States, critical deposition rates to prevent forest damage could not be identified.

They went on to say that "recognizing the paucity of data regarding sensitivity of major western Canadian tree species to atmospherically-deposited sulphur makes it virtually impossible to develop defensible target loadings for this ecosystem at the present time" (ESSA, 1987). For this reason, it was suggested that critical loadings developed to protect aquatic ecosystems be used, for the time being, to provide some protection to forest resources in the same regions.

Current deposition levels of 6 to 10 kg ha^{-1} a^{-1} in western Canada were suggested by ESSA (1987) to be adequate for sulphur requirements related to proper growth rates for trees. In addition, ESSA (1987) concluded that soils in the forested mountain watersheds of Alberta and British Columbia are not acting as sulphur sinks. As a consequence, elevated sulphur loadings will result in increased concentrations of mobile sulphate ions in soil waters, and likely leaching of plant nutrients.

The review by ESSA related to forestry resources recommended that critical loadings developed to protect aquatic ecosystems also be used to provide some protection to forest resources.

3.2 SOILS

Crop plants can require up to 18 kg ha^{-1} a^{-1} of sulphur (ESSA, 1987). Thus, moderate sulphur levels can be beneficial to many agricultural soils if these soils are sulphur deficient. ESSA (1987) concluded that "agricultural soils in western Canada are generally less susceptible to atmospheric acidic deposition than are forest soils".

The soils of most of southern Saskatchewan, southern and western Manitoba, and parts

of southern Alberta are of low sensitivity. In comparison, soils sensitive to acidic inputs are found in much of British Columbia, the Yukon, northern Saskatchewan, northcentral Alberta, and northern and eastern Manitoba. Many of these latter areas overlap regions on the aquatic sensitivity maps considered to be highly sensitive (Queen Charlotte Islands, coastal British Columbia and Vancouver Island, pockets in northeastern Alberta, northern Saskatchewan and the eastern portion of the Northwest Territories).

ESSA (1987) concluded that "it is still impossible to clearly establish dose-response relationships between sulphur inputs and response indicators like basic cation loss or Al mobilization, even for specific soils".

"In areas considered to have highly sensitive soils, but not having surface waters of high sensitivity, the establishment of scientifically defensible target loadings is more difficult" (ESSA, 1987). ESSA (1987) concluded that "target loading for surface waters would be adequate to protect peatlands as well".

The direct sensitivity of crops to acid-forming pollutants is of primary importance, but the sensitivity of the soils on which crops are grown is also important. Five areas identified by ESSA (1987) with moderate to high soil sensitivity and coinciding with major farming areas were:

(1) the area of Alberta west from Lesser Slave Lake
(2) a region of southwest-southcentral Alberta
(3) relatively small pockets of highly sensitive soils in central Saskatchewan
(4) the lower Fraser valley in southwestern British Columbia, and
(5) southcentral British Columbia

3.3 WATER

"Western Canada has many economically important fish species in regions with surface waters that are classed as being highly sensitive to acidification" (ESSA, 1987). Lake trout show declines in reproduction in the pH range from 5.4 to 5.6, while walleye are "one of the most sensitive species, showing declines in reproduction at pH 6.0-5.5" (ESSA, 1987).

"Empirical comparisons indicate damage to aquatic systems at wet deposition thresholds between 10 and 20 kg ha^{-1} a^{-1} of sulphate". (ESSA, 1987). However, no effect was reported to occur on lakes at the research forest near Haney, British Columbia when the loading was 18 kg ha^{-1} a^{-1} (ESSA, 1987). This was likely due to the great flushing occurring through the system.

It can be tempting to transfer monitoring results from one region to another. This has associated difficulties, since, there are different deposition levels and composition, climates, geology, soils, and aquatic life. However, ESSA (1987) noted that "the experiments conducted at ELA (Experimental Lakes Area) have special relevance to the

areas of Manitoba and Saskatchewan considered to be sensitive to acidic deposition, since both the terrain and fish communities are similar to those found at ELA" (ESSA, 1987). The ELA is an area located on the Canadian Shield and is not reflective of the prairie regions.

According to ESSA (1987), "dose-response information indicated that significant biological changes occur in aquatic systems when the mean pH reaches 5.8 - 6.0, and this range appears to be a reasonable threshold to use for establishing target loadings". In these shield lakes, a pH range from 5.8 to 6.0 corresponds to an alkalinity of about 10 to 40 $\mu eq\ L^{-1}$, water which would be classified as being highly sensitive.

Areas of western and northern Canada with waters classed as being highly sensitive to acidic inputs include coastal British Columbia, northern Saskatchewan, northwest and southeast Manitoba, an area near Jasper National Park, the northern upland regions of Alberta, the Canadian Shield in northeastern Alberta, and much of the eastern Northwest Territories. "Within these regions are several important fisheries, most notably salmon on the west coast, and lake whitefish, walleye, sauger, and lake trout in the inland areas" (ESSA, 1987).

3.4 FACTORS AFFECTING SULPHATE DEPOSITION

"In western Canada provinces, anthropogenic sulphur and nitrogen oxides emissions are significant percentages of the total emissions (80% and 48%, respectively)" (ESSA, 1987). Prevailing wind patterns for western Canada are generally from west to east, therefore sulphur emissions generated in the Pacific Northwest and coastal British Columbia potentially can impact the other parts of western and northern Canada.

"Existing loadings of acid-forming pollutants in western Canada are generally low and similar spatial patterns are exhibited for hydrogen ion, sulphate, and nitrate" (ESSA, 1987). This is not the case for Alberta.

In the southern prairies, alkaline particulate matter can influence precipitation chemistry. The dominant ionic constituents are calcium, sulphate, and ammonium, unlike the precipitation in eastern North America which is dominated by sulphate, hydrogen, and nitrate (Bertram et al., 1980). Consequently, there is no relationship between acidity and sulphate in precipitation, as is found elsewhere. Actual wet sulphate loadings ranged from 1.3 kg ha^{-1} a^{-1} near Yellowknife, N.W.T. to 23.3 kg ha^{-1} a^{-1} at Vancouver, B.C. The lowest pH levels were found in coastal British Columbia, where corrections for contributions from sea-salt are required.

Western and northern Canada differ from eastern North America in five important aspects. These are:

1. There are fewer major point sources in western and northern Canada.
2. Western and northern Canada contain large areas relatively insensitive to acidic inputs.
3. Western and northern Canada have areas receiving considerably more and considerably less precipitation than eastern Canada (ESSA, 1987).
4. Dispersion potential or ventilation capacity is less in western North America than in eastern North America.
5. The composition of precipitation in western and northern Canada is different from eastern Canada due to the presence of non-acidifying sulphate ions.

The **acidifying potential** concept developed by Brydges and Summers (1989) allows corrections to be made for non-acidic sulphate in precipitation. With this concept, the concentrations of calcium and magnesium in precipitation are subtracted from the sulphate concentration. In this way, the buffering effects of calcium and magnesium on acidifying components are taken into consideration. Brydges and Summers (1989) propose that their approach accounts for the net acidifying effect of nitrogen compounds when these compounds are taken up by vegetation.

4.0 RATIONALE FOR PROCESS

4.1 MEASUREMENT OF WET OR TOTAL DEPOSITION

Acidification can occur due to deposition of materials in either a wet or dry form. The principal acid precursors are ammonia and oxides of nitrogen and sulphur. However, sulphate and nitrate are the dominant anions in both short-term and long-term aquatic acidification.

The acidification potential of dry deposition is difficult to evaluate. There have not been many studies relating dry deposition rates to effects on different ecosystems. Dry deposition is difficult to measure but may be an important component of total acidic deposition. The only way at present to account for dry deposition is by modelling. Consequently, wet deposition will be used for interim critical loadings. Further investigation of the importance of dry deposition is required for western and northern Canada before the interim status of the critical loading can be removed. Data for dry deposition must be collected to verify the reliability of using wet deposition measurements.

4.2 RECEPTOR SENSITIVITY

The question of dealing with sensitivity classifications based upon the ability of soil and geology to reduce acidity or water bodies to buffer acidic inputs was addressed by preparing maps which combined ratings for the two receptors. Four general classifications were established. Class 1 defines areas where lake alkalinity is < 10 mg L^{-1} (high sensitivity) and the potential of soils and geology to reduce acidity is low; Class 2 areas have high sensitivity waters while soils and geology have a greater potential to reduce acidity; Class 3 areas have lake alkalinity ≥ 10 mg L^{-1} but soils and geology have low potential to reduce acidity and; Class 4 areas have lake alkalinity ≥ 10 mg L^{-1} and a greater potential of soils and geology to reduce acidity.

The maps illustrating these features for western and northern Canada are contained in Figures 1 to 5. The following is a breakdown for each classification.

Geographical Area	Class *(%)				Total $x10^6$ Land Area (ha)
	Class 1	Class 2	Class 3	Class 4	
British Columbia	9.2	1.7	26.0	59.6	93.1
Alberta	1.1	1.0	10.6	87.1	66.1
Saskatchewan	14.0	0.6	22.3	63.0	65.3
Manitoba	2.7	0.1	31.9	65.3	64.9
Northwest Territories	22.7	2.9	24.4	41.5	297.0

* Areas of glaciers and ice not included, therefore percentages may not total 100%.

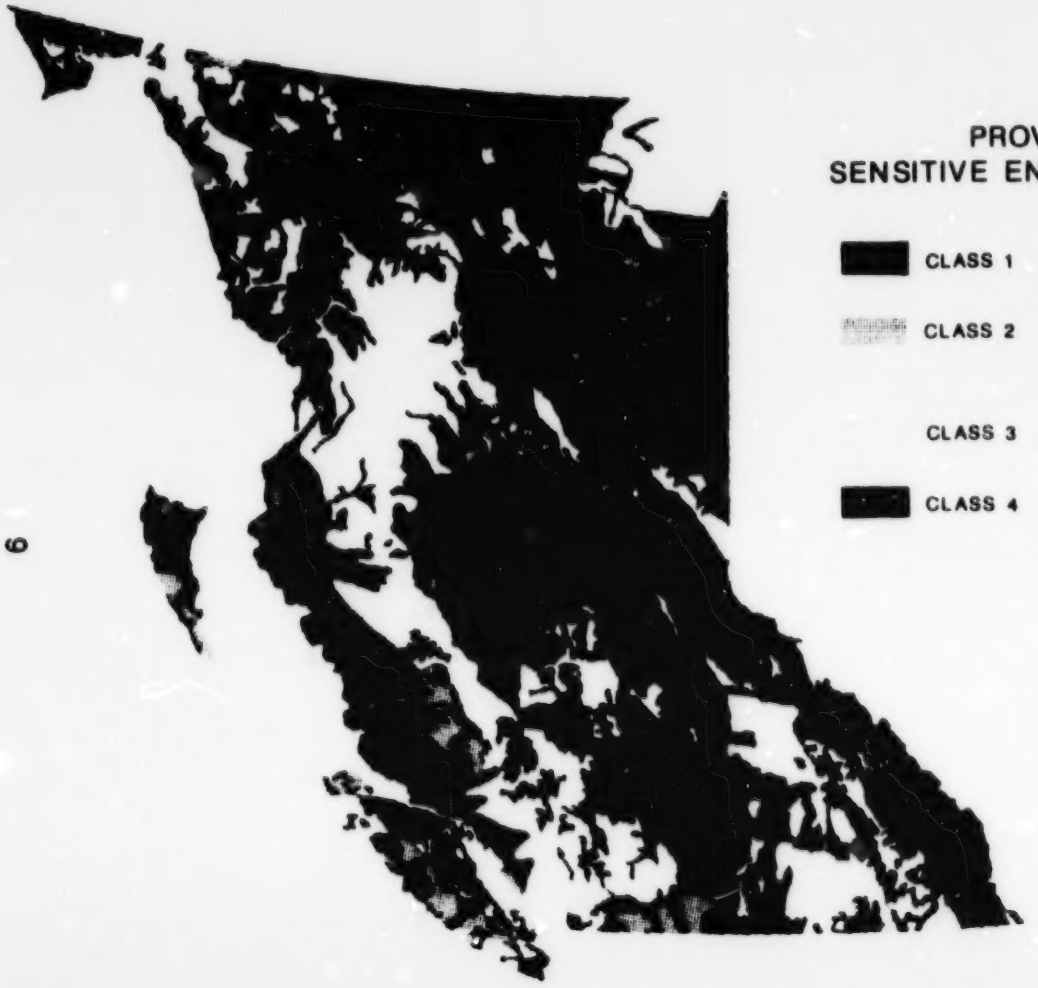


FIGURE 1

PROVINCE OF BRITISH COLUMBIA
SENSITIVE ENVIRONMENTS TO ACIDIC DEPOSITION

■	CLASS 1	Lake alkalinity < 10 mg/l. Potential of Soils and Geology to reduce acidity is LOW.
▒	CLASS 2	Lake alkalinity < 10 mg/l. Potential of Soils and Geology to reduce acidity is MODERATELY LOW, MODERATELY HIGH, HIGH. (May contain areas of ICE)
	CLASS 3	Lake alkalinity ≥ 10 mg/l. Potential of Soils and Geology to reduce acidity is LOW.
■	CLASS 4	Lake alkalinity ≥ 10 mg/l. Potential of Soils and Geology to reduce acidity is MODERATELY LOW, MODERATELY HIGH, HIGH. (May contain areas of ICE)

FIGURE 2
PROVINCE OF ALBERTA
SENSITIVE ENVIRONMENTS TO ACIDIC DEPOSITION

CLASS 1 Lake alkalinity < 10mg/L ; Potential of Soils and Geology to reduce acidity is LOW

CLASS 2 Lake alkalinity < 10mg/L; Potential of Soils and Geology to reduce acidity is MODERATE or HIGH

CLASS 3 Lake alkalinity ≥ 10mg/L; Potential of Soils and Geology to reduce acidity is LOW

CLASS 4 Lake alkalinity ≥ 10mg/L; Potential of Soils and Geology to reduce acidity is MODERATE or HIGH

FIGURE 3

PROVINCE OF SASKATCHEWAN
SENSITIVE ENVIRONMENTS TO ACIDIC DEPOSITION

CLASS 1	Lake alkalinity < 10mg/L ; Potential of Soils and Geology to reduce acidity is LOW
CLASS 2	Lake alkalinity < 10mg/L; Potential of Soils and Geology to reduce acidity is MODERATE or HIGH
CLASS 3	Lake alkalinity > 10mg/L; Potential of Soils and Geology to reduce acidity is LOW
CLASS 4	Lake alkalinity > 10mg/L; Potential of Soils and Geology to reduce acidity is MODERATE or HIGH

FIGURE 4
PROVINCE OF MANITOBA
SENSITIVE ENVIRONMENTS TO ACIDIC DEPOSITION

CLASS 1 — Lake alkalinity < 10mg/L, Potential of Soils and Geology to reduce acidity is LOW

CLASS 2 — Lake alkalinity < 10mg/L, Potential of Soils and Geology to reduce acidity is MODERATE or HIGH

CLASS 3 — Lake alkalinity ≥ 10mg/L, Potential of Soils and Geology to reduce acidity is LOW

CLASS 4 — Lake alkalinity < 10mg/L, Potential of Soils and Geology to reduce acidity is MODERATE or HIGH

FIGURE 5
NORTHWEST TERRITORIES
SENSITIVE ENVIRONMENTS TO ACIDIC DEPOSTION

	CLASS 1	Lake alkalinity < 10mg/L ; Potential of Soils and Geology to reduce acidity is LOW
	CLASS 2	Lake alkalinity < 10mg/L; Potential of Soils and Geology to reduce acidity is MODERATE or HIGH
	CLASS 3	Lake alkalinity ≥ 10mg/L; Potential of Soils and Geology to reduce acidity is LOW
	CLASS 4	Lake alkalinity ≥ 10mg/L; Potential of Soils and Geology to reduce acidity is MODERATE or HIGH (May contain areas of organics - not rated)
	CLASS 5	ice

The Task Group has assumed that Class 1 and 2 areas require identical levels of protection since both have lakes with a high sensitivity to acidic inputs. The Class 2 areas are generally small in comparison to Class 1, are immediately adjacent to Class 1, and can be considered as areas of transition.

Class 4 areas do not require the same high level of protection as Classes 1 and 2, since lakes have moderate or low sensitivity, and the potential of soils and geology to reduce acidity is moderately low to high, or definitely high.

Class 3 areas have a highly sensitive terrestrial environment but an aquatic environment with low sensitivity. Therefore, for the interim, the Task Group recommends that these areas be provided the same level of protection as Classes 1 and 2. Less stringent levels of protection may be considered in the future if research indicates that soils or geological formations can withstand higher levels of acidification. Since loadings will be determined on the basis of effects levels in the most sensitive area, a significant margin of safety will exist in areas which are not as highly sensitive. Further research should be undertaken to determine the level of protection required for Class 3 areas.

4.3 LEVEL EXPRESSED AS A CONCENTRATION OR LOADING

Critical levels can be expressed either as a concentration or as a load. In fact, Brydges and Summers (1989) discuss the **acidifying potential (AP)** as both a loading and a concentration. In areas such as western and northern Canada, there are large variations in the amount of precipitation. In some areas (e.g. in British Columbia), precipitation can vary from greater than 3 500 mm along the coast to less than 300 mm near interior locations such as Kamloops (Kotturi, 1990). Thus, in most areas of western and northern Canada, the level should be expressed as a loading rather than a concentration.

High volumes of precipitation lead to higher flushing rates through lakes which in turn can mitigate higher loadings of materials in aquatic systems. "The relationships between surface water chemistry and hydrology in some areas of the United States make it necessary to develop separate critical loads for different hydrologic types, and critical loads could then be set to protect the most sensitive type of lake in an area" (Henriksen and Brakke, 1988). With respect to this type of situation, Henriksen and Brakke (1988) also noted that at "a constant concentration, greater amounts of precipitation give a greater calculated load but the biological effect remains the same". Additional site-specific studies should be undertaken in areas of greater amounts of precipitation such as coastal British Columbia to determine the critical loading which corresponds to "no effect".

4.4 THE RECOMMENDED PROCESS

Methods for determining the critical loading and estimating acidic deposition for northern and western Canada should take into account the diversity of the region. For example, it should account for the acidifying factors of sea-salts on the west coast and the

presence of non-acidic sulphate in precipitation in the prairie regions. It should also consider the fact that the amount of precipitation varies considerably across the region.

The **AP** concept, calculated as follows, can account for the aforementioned variables.

$$AP = SO_4^{=} - (Ca^{++} + Mg^{++}) \text{ ... expressed as } \mu eq\ L^{-1}$$

When precipitation rates are taken into account, the AP loading is expressed as meq m^{-2} a^{-1}.

For example, if a highly sensitive lake is located in an area which receives 0.5 m a^{-1} runoff and the lake has 100 μeq L^{-1} buffering, the present cation production is the product of 500 L m^{-2} a^{-1} multiplied by 100 μeq L^{-1}, equating to 50 meq m^{-2} a^{-1}. To maintain a bicarbonate system with 50 μeq L^{-1} buffering in the runoff water, the system can lose 50 μeq L^{-1} (100 μeq L^{-1} - 50 μeq L^{-1}), or the equivalent of 25 meq m^{-2} a^{-1}. This would be the critical AP to prevent the on-set of damage for this type of lake.

The concept of AP has only one idiosyncrasy, and that is in certain situations, a negative value is calculated for AP in precipitation. This means acidification is not occurring at that location, but rather that buffering is being imparted (i.e., negative acidification) by the precipitation.

Although the AP has not been applied by other jurisdictions, the concept of accounting for neutralized sulphate is taken into account in the empirical approach used in eastern Canada. One major important benefit of AP is that once a critical AP is selected, it will be possible to predict how new sources of acid will impact the AP. For example, if the critical loading has been selected at an AP of 10 meq m^{-2} a^{-1}, and if a certain area already receives 8 meq m^{-2} a^{-1}, the AP from any new sources must remain below 2 meq m^{-2} a^{-1}. If the area receives 500 mm of precipitation, the new total acid forming emissions from all new sources must not produce an average AP in precipitation of more than 4 μeq L^{-1}.

Brydges and Summers (1989) also introduce a net AP which takes into account nitrogen leached from the watershed. To account for this, nitrate in runoff should be measured and included in the AP equation. Since the significance of nitrate leaching in northern and western Canada is not known at this time, monitoring to address this information gap should be undertaken.

4.4.1 EXISTING AP LEVELS IN WESTERN AND NORTHERN CANADA

Data for 1987 (most recent year with complete records for all the provinces except Saskatchewan where the most recent data were for 1986) were used to determine the existing AP levels in precipitation for the western provinces (Appendix 1). The loadings are as follows:

Province	No. of Stations	Range of AP Loading meq m^{-2} a^{-1}	Comments
British Columbia	11	-36.4 to 62.5	High near Vancouver
Alberta	11	-44.6 to 8.1	Only 3 stations +AP
Saskatchewan	5	4.3 to 9.7	All stations in North
Manitoba	8	-27.1 to 2.2	Only 3 stations +AP

A contour map depicting these existing AP loadings in precipitation has been developed (Figure 6). As anticipated, large areas of the prairie region have negative AP values indicating that acidification is not of concern at this time. A large area of northern Saskatchewan and western Manitoba, as well as a small area of Alberta near Edmonton have positive AP values which are less than 10 meq m^{-2} a^{-1} . British Columbia has large areas of negative or low AP values, but also some very high positive AP values near the coast just north from Vancouver and near Prince Rupert. These latter areas receive large quantities of precipitation in relation to the remainder of western and northern Canada.

4.4.2 EXISTING POTENTIAL TO MITIGATE EFFECTS

The principal buffering system in most fresh waters is the carbonic and bicarbonate equilibrium, although organic substances and metal hydroxides can be effective buffers at low pH. Attention has been focussed on lakes with high sensitivity, i.e., those lakes with less than 200 μeq L^{-1} of alkalinity.

The highest AP loadings calculated for western Canada were for the Seymour Dam station located to the north of Vancouver, where the AP was 62.5 meq m^{-2} a^{-1}. Coincidently, Seymour Lake, formed behind the dam, is one of three lakes used as a water supply for Greater Vancouver. As part of an extensive quality control program, pH has been measured for the water intake three to four times per week, since 1959. Whitfield (unpublished) has performed a statistical analysis for the pH data for Seymour Lake and determined that "pH has shown a decrease over the past 25 years on a linear basis". The decrease was in the order of 0.2 units. The empirical "loading-effect" relationship for this particular coastal site in British Columbia indicates that in fact, an AP loading of about 60 meq m^{-2} a^{-1} in precipitation, may cause increased acidity in such water bodies.

The average concentration of alkalinity (buffering) in Seymour Lake in 1989 was 70 μeq L^{-1}. Maintaining a 50 μeq L^{-1} concentration in the lake corresponds to maintaining a bicarbonate system. Consequently, the concentration could be depleted by 20 μeq L^{-1}. Based on a net precipitation (minus evapotranspiration) of 2 800 mm, the lake could receive an AP of 56 meq m^{-2} a^{-1}. This calculation assumes no additional uptake of acid by increased weathering rates; however, Henriksen and Brakke (1988) used a factor of 0.2 (cited as a conservative average) to account for the weathering rate increase due to

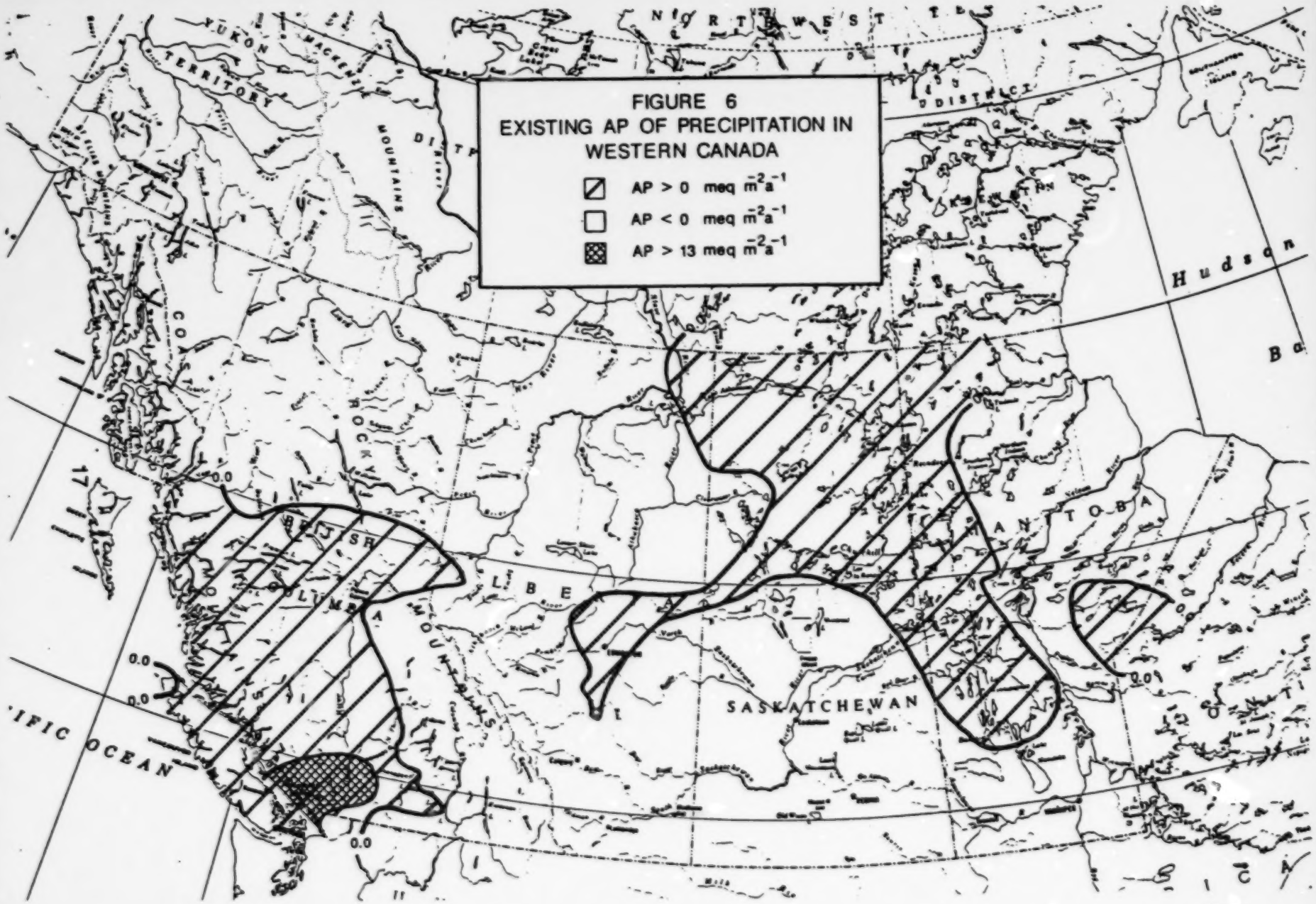


FIGURE 6
EXISTING AP OF PRECIPITATION IN WESTERN CANADA
AP > 0 meq m⁻²a⁻¹
AP < 0 meq m⁻²a⁻¹
AP > 13 meq m⁻²a⁻¹
YUKON TERRITORY
MACKENZIE DISTRICT
NORTHWEST TERRITORIES
MOUNTAINS
ROCKY
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
Hudson Bay
PACIFIC OCEAN
0.0

increased acidification.This means that Seymour Lake could likely receive an AP of about 67 meq m^{-2} a^{-1} and still maintain 50 μeq L^{-1} alkalinity and remain bicarbonate.

To compare to an area receiving considerably less precipitation, data for Cree Lake in northern Saskatchewan were handled in a similar manner. Without applying a weathering factor, the critical load developed for Cree Lake while maintaining a bicarbonate system in Cree Lake is 12.7 meq m^{-2} a^{-1}.

Both empirical models and analytical data can be used to estimate critical loadings. "The most conservative approach would be to determine directly by titration the amount of acid required to acidify specific lake waters to a pre-determined pH" (D. Trew 1988). Such an approach could be considered as a "worst case" since watershed acidification processes, hydraulic flushing, and in-lake alkalinity generation are ignored.

To use this approach requires that information be available on the actual titration curve for each lake. Such information is generated regularly by laboratories in the determination of alkalinity values, but seldom saved for further reference. The Task Group was fortunate that such data were available for some lakes with high sensitivity in Alberta (n=2), and a large number in British Columbia (n=96).

The amount of acid required to be added to reduce the pH in a lake to 6.0 (equivalent to an alkalinity of about 50 μeq L^{-1}) depends on the buffering available (alkalinity) and the volume of the lake relative to the lake area. This relationship equates to the mean lake depth. When multiplied by the amount of acid determined to reduce the pH to 6.0 for each lake, the **AP** was estimated for each lake, assuming that the loading could continue for a 100 year period.

The mean lake depth varies with region, but knowing that shallow lakes in the prairie region would have serious problems with respect to freezing solid, turning anoxic, etc. a mean lake depth for most areas of 5.0 metres was selected (i.e., problems other than acidification are more important in these shallow lakes). For Alberta, this resulted in critical loadings for the two highly sensitive lakes in northeastern Alberta ranging from 4.0 to 4.9 meq m^{-2} a^{-1}. It is likely that values for lakes in Saskatchewan and Manitoba would be more like those in Alberta than those in British Columbia, due to similar geology and climate.

For British Columbia, the actual mean lake depths were used to calculate buffering. This reduced the number of highly sensitive lakes with useful data to 49. The calculated critical loadings for these lakes ranged from 0.03 to 114 meq m^{-2} a^{-1}, with a mean critical loading of 11.7 meq m^{-2} a^{-1} and a median of 3.9 meq m^{-2} a^{-1}. A shorter timeframe than 100 years (say 50 years) would increase the calculated allowable loadings.

These calculated AP numbers for the Alberta and British Columbia lakes are "worst-case" critical loadings, based simply upon the presence of alkalinity in the water, with no

provision being made for the replenishment of the buffering capacity by in-lake processes or from other sources in the watershed.

4.4.3 A LITERATURE REVIEW OF AP LEVELS WHICH IMPACT ON RESOURCES

Numerous predictive empirical models exist on which to estimate interim critical loadings. Presently, there are no regional models which will provide the "correct" critical loading for western and northern Canada. Only models from other jurisdications could be used to estimate an interim critical loading.

In most areas of the world where acidification damage has been documented, the wet sulphate loading has been calculated since non-acidic sulphates were determined to be negligible. The Task Group reviewed and modified a number of models stoichometrically to express the critical loadings in terms of equivalents.

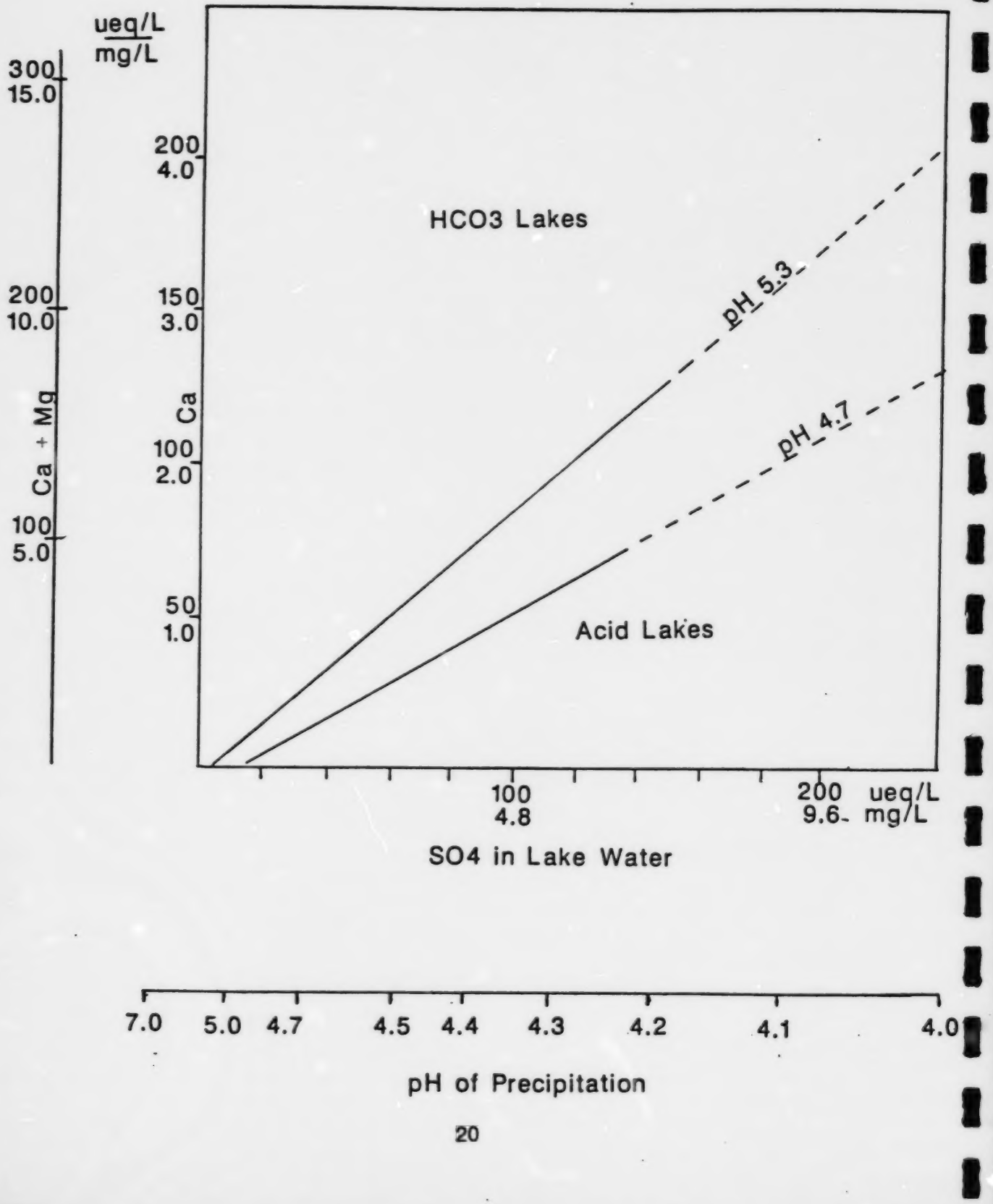
In 1985, the Minnesota Pollution Control Agency (MPCA) issued a Statement of Need and Reasonableness related to a proposed acid deposition standard of 11 kg SO_4 ha^{-1} a^{-1} and a control plan. The document indicated that modelling takes on a conservative nature since in-lake alkalinity generation is not considered (MPCA, 1985). It also concluded that each of the approaches tended to converge on the wet sulphate deposition rate of 11 kg ha^{-1} a^{-1} (equivalent to an AP of 22.9 meq m^{-2} a^{-1}), based on an effects threshold pH of 4.7 in precipitation. There is no evidence that the effects threshold pH for precipitation in western Canada is 4.7.

Henriksen (1980) developed a nomograph (Figure 7) to relate stages of acidification to levels of precipitation pH. The nomograph was constructed using data for small lakes in south Norway, and was verified for large lakes in northern Norway. Lakes are grouped into three classes: bicarbonate dominated (pH > 5.3) with good fish populations; transition lakes (pH 4.7 to 5.3) with sparse fish populations; and strong acid lakes (pH < 4.7) which are barren of fish. The nomograph cannot be used for Alberta (Trew, 1988) since the mean annual pH of precipitation in Alberta is 5.5 (outside the range of the nomograph's x-axis). The SO_4 in precipitation axis does not apply to Alberta because of the presence of significant quantities of calcium and magnesium, and the sulphate in lakewater axis is inapplicable since there is no documented correlation between acidity and sulphate in Alberta lakes (Trew, 1988).

ESSA (1987) indicated that below a lake pH of 5.8, some damage could occur, and that in relatively clear surface waters, this corresponded to an alkalinity of 32 μeq L^{-1}. For western Canada, the Task Group has decided that a critical loading should be developed to maintain a minimum lake pH of 6.0 where values are currently above pH 6.0. Naturally acidic brown-water systems, where the pH is less than 6.0, are not addressed in this analysis, and more work needs to be done to determine critical loadings to protect these ecosystems.

FIGURE 7

HENRIKSEN NOMOGRAPH



ESSA (1987) noted that previous studies had recommended critical loadings in the range from 10 to 20 kg SO_4 ha^{-1} a^{-1} as wet deposition, corresponding to a mean precipitation pH from 4.3 to 4.8. The corresponding AP values are from 20.8 to 41.6 meq m^{-2} a^{-1}.

Using a series of curves (Figure 8) based on lakes throughout Scandinavia, Dickson (1983) related the effects of various wet sulphate loadings on the pH values in lakes with varying base production potential. As noted earlier, the Task Group recommends that the lake pH should be maintained at or above pH 6.0. To ensure this, high sensitivity western and northern Canadian lakes, based on the Dickson curves, could receive a loading of about 6 kg SO_4 ha^{-1} a^{-1} (AP of 12.5 meq m^{-2} a^{-1}). This loading would increase to 10 kg SO_4 ha^{-1} a^{-1} to maintain the lake pH $\geq$ 5.3 (AP of 20.8 meq m^{-2} a^{-1}).

A five-day workshop held in Sweden in 1988 developed numerous conclusions and recommendations based on data and papers made available prior to the workshop and on input from attendees. Estimated critical loads for sulphur based on the most sensitive receptor within different geographical areas are in Table 1. Generally, for all geographical areas discussed, wet sulphate loadings of 10 kg ha^{-1} a^{-1} (AP of 20.8 meq m^{-2} a^{-1}) would protect sensitive lakes. Exceptions to this include Sweden where the Dickson (1983) model predicted a loading of 7.5 kg ha^{-1} a^{-1} (AP of 15.6 meq m^{-2} a^{-1}), while the Schindler (1988) model based on eastern North America and Sweden required a loading of between 9 to 14 kg ha^{-1} a^{-1} (AP of 18.7 to 29.1 meq m^{-2} a^{-1}).

4.4.4 RECOMMENDED CRITICAL LOADINGS TO PROTECT HIGHLY SENSITIVE ENVIRONMENTS

The use of the Dickson curves in conjunction with the maintenance of a lake pH of 6.0, leads to the maximum acceptable loading of 12.5 meq m^{-2} a^{-1} to protect lakes with 20 to 90 μeq L^{-1} buffering and 31 meq m^{-2} a^{-1} for lakes with 110 to 160 μeq L^{-1} buffering. The "worst-case" analysis of what AP highly sensitive lakes could tolerate indicated a loading from 4 to 4.9 meq m^{-2} a^{-1} for Alberta, and a median of 4 meq m^{-2} a^{-1} (mean of 12 meq m^{-2} a^{-1}) for British Columbia. In terms of the present loadings occurring in the western provinces, a level of 12.5 meq m^{-2} a^{-1} is higher than the current measured maximum of 2.2 meq m^{-2} a^{-1} for Manitoba, 9.7 meq m^{-2} a^{-1} for Saskatchewan, and 8.1 meq m^{-2} a^{-1} for Alberta, but not for many coastal areas of British Columbia (stations located near significant emission sources). Values in British Columbia below 12.5 meq m^{-2} a^{-1} were measured in 1987 at seven of eleven stations (see Appendix 1).

The Task Group recommends a range of interim critical loadings, expressed as AP, of 12 to 31 meq m^{-2} a^{-1} for all areas of western and northern Canada except brown-water systems and coastal British Columbia. This range of critical loads is virtually identical to one determined for Alberta using a model developed for Quebec (Alberta Environment, 1990).

FIGURE 8

DICKSON CURVES

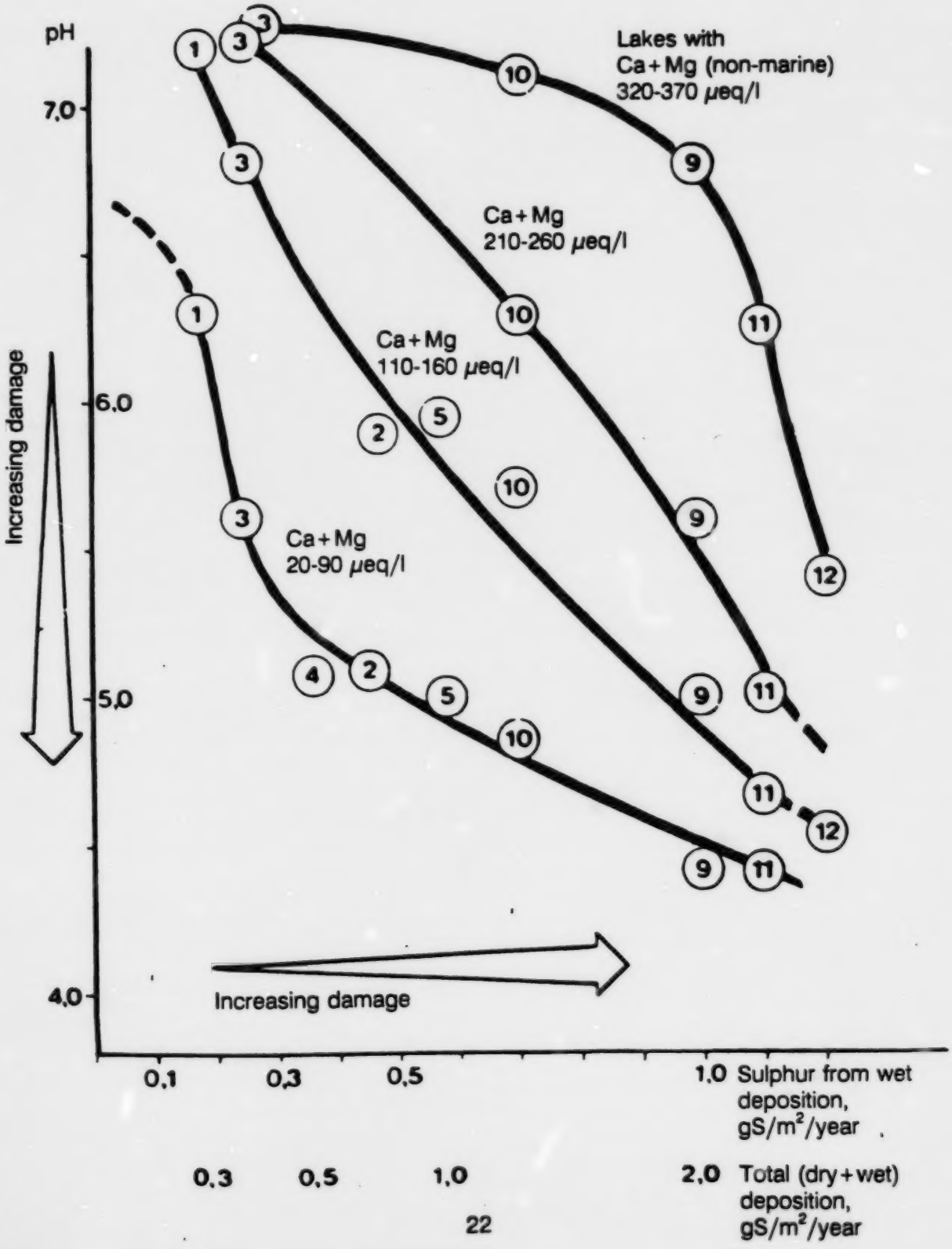


TABLE 1

CRITICAL WET SULPHATE LOADINGS PROPOSED FOR DIFFERENT AREAS

MODEL	Wet SO_4 Loadings ($kg\ ha^{-1}\ a^{-1}$)	AP ($meq/m^2/a$)
Henriksen Nomograph in conjunction with ESSA (1987) data	11.5	23.9
Dickson Curves (lake pH ≥ 5.8)	7	14.6
Dickson Curves (lake pH ≥ 5.3)	10	20.8
MPCA (borderline potential effects - sensitive lakes) (based on Almer et al, 1978)	9-12	18.7-25
From ESSA (1987):		
Brydges and Neary (1984)*	< 15	< 31.2
Oppenheimer (1984)*	< 18	< 37.4
Henriksen (1980)	10-12	20.8-41.6
MPCA (1985)	11	22.9
From Nordic Council/UN ECE (1988)		
Dickson (1986)* - Sweden	7.5	15.6
Henriksen et al. (1986) (Precipitation 1 000 mm) Norway	10	20.8
Schnoor and Stumn (1987)* - Switzerland	10-25	20.8-52
Gorham (1984)* - Eastern North America	15	31.2
Schuurkes (1986)* - Netherlands	12.5	26
Henriksen and Brakke (1988)		
Adirondacks	17	35.4
Upper Michigan	10	20.8
Upper Great Lakes	15.5	32.2
Wright et al. (1988)*		
Norwegian and Swedish Lakes	10	20.8
Finnish Lakes	10-65	20.8-135
Schindler (1988)		
Eastern N. America and Sweden	9-14	18.7-29.1

* References found in ESSA (1987), Nordic Council/UN ECE (1988) or this document.

In terms of the ability of receptors to tolerate a loading of 12 meq m^{-2} a^{-1}, over a 100 year period, the two highly sensitive lakes in Alberta could apparently not tolerate this load while 39 of the 49 highly sensitive lakes in British Columbia are predicted to be impacted over a 100 year period. Lakes in Manitoba and Saskatchewan likely would be similar in nature to those in Alberta.

The proposed range for the interim critical loading is inprecise since it is assumed that the Dickson curves are applicable for western and northern Canada. However, these curves yield a conservative estimate of AP loadings to maintain lake pH values ≥ 6.0. This loading is not exceeded in most of western Canada, in areas where the Task Group members feel that there has been no apparent acidification. The proposed range of interim critical loadings of 12 to 31 meq m^{-2} a^{-1} is sufficiently restrictive to protect highly sensitive ecosystems in the short-term. A value has to be determined for brown-water systems and coastal British Columbia, and a number of recommendations have been included to accomplish this goal.

The British Columbia Ministry of Environment has been monitoring six lakes on a monthly basis since 1984 in some of the areas receiving loadings greater than 12 meq m^{-2} a^{-1}, in order to determine if acidification is occurring. A preliminary assessment of these data is to occur in late 1990. This assessment will indicate whether short-term effects are apparent at loadings greater than 12 meq m^{-2} a^{-1}. The British Columbia Ministry of Environment should continue this monitoring.

4.5 SEA-SALT CORRECTIONS

In developing the concept of AP (Brydges and Summers, 1989), the need to apply a correction factor for sea-salt was discussed. It was shown that for eastern Canada, to correct SO_4^{--}, Ca^{++},and $Mg^{++}$for sea-salt resulted in an overall change in acidifying potential of less than 1 μeq L^{-1}. "Since 1 μeq L^{-1} is well within the error bounds of the concentration measurements it is not essential, therefore, to make a correction to the AP for sea-salt, even in coastal areas." (Brydges and Summers, 1989).

To determine if ignoring the sea-salt correction was also applicable for western and northern Canada and in particular coastal British Columbia, the precipitation data for 1987 at a number of coastal stations were used to determine the AP, both with and without the sea-salt correction being applied. The following are the results of that analysis.

The data indicate that the AP concentrations when corrected for the presence of sea-salt increase from 1.3 to 4.9 μeq L^{-1}. These values for British Columbia are not insignificant and should not be neglected.

Station	Monitoring Data (μeq/L)					Sea-salt Corrected (μeq/L)				
	Na^+	SO_4^-	Ca^{++}	Mg^{++}	AP	SO_4^-	Ca^{++}	Mg^{++}	AP	AP*
Spectacle L.	31.8	16.2	9.0	7.4	-0.2	12.4	7.6	0.1	4.7	+
Vancouver	27.4	40.4	14.5	6.6	19.3	37.0	13.3	0.4	23.3	+
Squamish	26.1	35.8	9.0	3.3	23.5	32.6	7.8	-3.0	27.8	24.8
Nanoose	32.2	30.8	12.0	5.8	13.0	28.1	10.6	-1.5	19.0	17.5

* AP values when -Mg^{++}concentrations are set at zero.

\+ No change to the initial AP with sea-salt correction of 0.103 times Cl^- subtracted from the total SO_4.

5.0 CONCLUSIONS

The ESSA report indicated that critical loads should be based on highly sensitive or moderately sensitive aquatic environments. Where aquatic sensitivity is low but soil sensitivity is high, critical loads should be based on protection of soil.

In preparing interim critical loadings, the Task Group recommends that Class 1, 2, and 3 areas be classified as being highly sensitive to acidic inputs and that highly sensitive areas should receive the smallest acidic loadings. Class 4 areas can receive more acidic deposition.

An interim critical load range of 12 to 31 meq m^{-2} a^{-1} based upon AP is recommended for western and northern Canada, exclusive of brown-water systems and coastal British Columbia. Since the proposed range of interim critical loadings is based upon effects levels in highly sensitive areas, a significant margin of safety will exist in areas which are not as sensitive. It is recommended that the British Columbia Ministry of Environment continue studies and research to determine interim critical loads for coastal areas, and that all jurisdictions undertake work to determine critical loadings for brown-water systems.

Large areas of the prairie region have negative AP values, indicating that acidification is not of concern at this time. A large area of northern Saskatchewan and western Manitoba, as well as a small area of Alberta near Edmonton have positive AP values which are well below 12 meq m^{-2} a^{-1} . British Columbia has large areas of negative or low AP values, but also some very high positive AP values along the coast just north from Vancouver, as well as near Prince Rupert.

6.0 RECOMMENDATIONS

The Task Group feels that the word "interim" can be removed from the range of critical loadings when sufficient data from western and northern Canada have been collected. The recommendations for further studies, provided below, can be used as a starting point. These are not presented in a priorized order.

1. That data for dry deposition be collected to verify the reliability of using only wet deposition measurements.

2. Research should be undertaken to determine the level of protection required for Class 3 areas, those areas which are transition between high and low sensitivity areas. These areas have lakes with moderate or low sensitivity and a low potential for soils and geology to reduce acidity.

3. Additional data collection should be undertaken in areas with greater amounts of precipitation, such as coastal British Columbia, to determine more accurately the critical loading which corresponds to "no effect".

4. Monitoring should be undertaken in areas receiving high AP loadings to determine if watershed leaching of nitrogen is taking place and causing further acidification.

5. More work needs to be done on acidic brown-water systems to determine critical loadings to protect these ecosystems.

6. The British Columbia Ministry of Environment should continue monitoring highly sensitive lakes in areas receiving loads greater than the recommended interim critical load in order to determine if acidification is occurring.

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APPENDIX 1

CALCULATED AP LOADINGS (meq m^{-2} a^{-1}) BY PROVINCE FOR EACH STATION

British Columbia (1987 data)

Nanoose Bay	7.7	Port Hardy	-17.3
Seymour Dam	62.5	Kitimat	23.3
Squamish	50.1	Vancouver	16.5
Victoria	6.9	Smithers A	-10.1
Cranbrook A	-36.4	Kelowna	0.6
Kamloops	2.0		

Alberta (1987 data)

Ft. Vermillion	-9.3	Ft. McMurray	-12.2
High Prairie	-12.8	Beaverlodge	-2.7
Whitecourt	-6.6	Cold Lake	0.4
Edmonton	8.1	Red Deer	1.2
Calgary	-3.2	Kananaskis	-31.8
Suffield	-44.6		

Saskatchewan (1986 data)

Kane Lake	8.9	Dreaver Lake	5.6
Stony Rapids	9.7	Cree Lake	6.0
Pelican Narrows	4.3		

Manitoba (1987 data)

Island L. (Prov)	1.6	Island L.(Fed)	2.2
Brochett	2.1	Gillam	-8.0
Norway House	-1.9	Winnipeg	-27.1
Pointe du Bois	-1.8	McCreary	-0.6

APPENDIX 2

CONVERSION OF WET SULPHATE LOADS (kg ha^{-1} a^{-1}) TO AP (meq m^{-2} a^{-1})

To convert a load of 11 kg $SO_4^=$ to meq m^{-2} a^{-1}:

1 ha = 10 000 m^2

11 kg $SO_4^=$ is 11 000 grams $SO_4^=$

To obtain g m^{-2} : divide 11 000 g by 10 000 m^2

= 1.1 g $SO_4^=$ m^{-2} a^{-1} .....(1)

We have to convert this weight per unit area per time into meq.

1 mg $SO_4^=$ = 20.8 μeq $SO_4^=$

or 1 g = 20.8 meq .....(2)

Multiplying equation (1) by (2) yields :

(1.1 g $SO_4^=$ m^{-2} a^{-1}) * (20.8 meq per g $SO_4^=$)

= 22.88 meq m^{-2} a^{-1}

= 22.9 meq m^{-2} a^{-1}

GLOSSARY

kg ha^{-1} a^{-1}	: kilograms per hectare per year
meq m^{-2} a^{-1}	: milliequivalents per square metre per year
mg L^{-1}	: milligrams per litre
μeq L^{-1}	: microequivalents per litre
LRTAP	: Long Range Transport of Air Pollutants